Circadian and ultradian rhythms in sleep structure and body temperature during an ultrashort sleep-wake schedule

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CIRCADIAN EXPERTS IN SHIFTWORK AND EXTENDED HOURS

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OBJECTIVE & STUDY DESIGN

- Historical research on sleep-wake rhythm: short (1 h wake / 2 h attempted sleep) and ultrashort (7 min wake / 13 min attempted sleep) sleep-wake schedules [WEITZMAN ET AL 1974, CARSKADON & DEMENT 1977, LAVIE 1986, LAVIE & SEGAL 1989] ➲ strong circadian drive of sleep propensity revealed, with maximum around 5 to 7 a.m. and minimum around 9 to 10 p.m.

- Adaption of ultrashort sleep-wake schedule design in order to …
  1. assess circadian drive of various physiological and subjective variables in comparison to well established circadian marker: core body temperature
  2. compare classic method of core body temperature measurement (rectal) to novel method (aurical, i. e. within the ear)
  3. investigate phase relationship between potential circadian-driven variables

- Study design: 50 hours of alternation between 20 min wakefulness and 10 min of rest (with the instruction to fall asleep as fast as possible)
- Continuous EEG, ECG and body temperature recording
- Rating of subjective sleepiness during wakefulness on a visual-analogue scale
- 12 young healthy volunteers; 8 subjects (4/4 male/female, 23.4 ± 4.7 years, range: 18-30 years) completed their trial

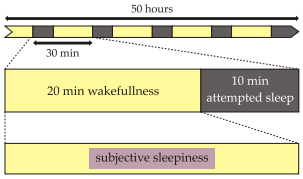


Fig. 1: Study design – the ultrashort sleep-wake schedule

Figs. 2-4: (left) Schematic of aurical temperature measurement. (middle) Subject wired-up for trial. (right) Visual analogue scale for subjective sleepiness rating.

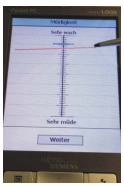
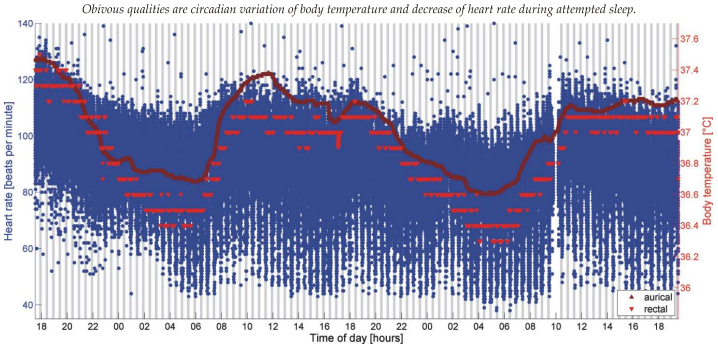
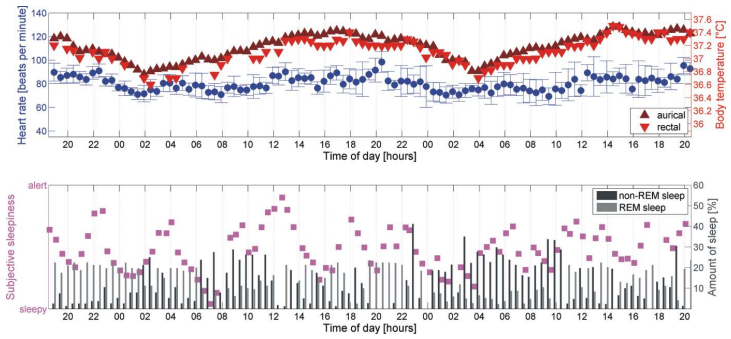


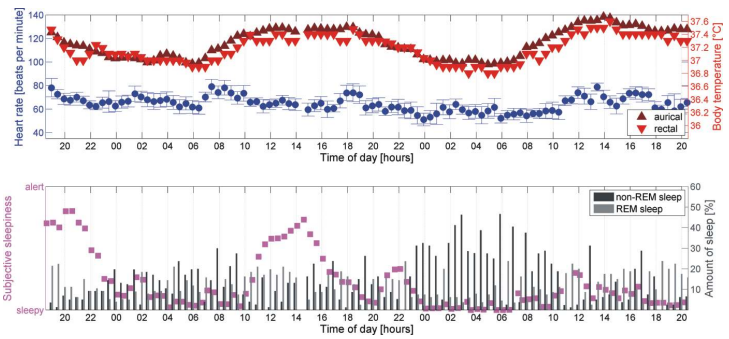
Fig. 5: Continuous heart rate and body temperature of subject n° 8 during alternation of wake and attempted-sleep (grey bars) episodes. Obivous qualities are circadian variation of body temperature and decrease of heart rate during attempted sleep.



DATA ANALYSIS & RESULTS

Figs. 6-7: Subjects n° 4 & 12 (left & right figure, respectively). Following measures were averaged over each attempted-sleep episode: aurical & rectal body temperature, heart rate (HR) and heart rate variability (HRV) in the upper panel. Amount of non-REM and REM sleep in the lower panel. Additionally, lower panels show subjective sleepiness (SS), specified during wake episodes. Ratings of subjective sleepiness clearly show circadian as well as ultradian periodic behaviour. During periods of increased body temperature, a decrease of non-REM sleep can be observed. Also, the amount of non-REM is accumulating in the second half of the trial. While amount of non-REM sleep in the second night is peaking, the amount of REM sleep is vanishing.





Tab. 1: Correlation coefficents of averaged sleep-episode measures of subject n° 4 (see also fig. 6)

	aurical	rectal	HR	HRV	nREM	REM	SS
aurical	—	0,945	0,592	0,162	-0,355	0,225	0,314
rectal	0,945	—	0,537	0,131	-0,333	0,182	0,314
HR	0,592	0,537	—	0,058	-0,623	0,554	0,403
HRV	0,162	0,131	0,058	—	-0,059	-0,159	0,058
nREM	-0,355	-0,333	-0,623	-0,059	—	-0,735	-0,174
REM	0,225	0,182	0,554	-0,159	-0,735	—	0,098
SS	0,314	0,314	0,403	0,058	-0,174	0,098	—

Tab. 2: Correlation coefficents of averaged sleep-episode measures of subject n° 12 (see also fig. 7)

	aurical	rectal	HR	HRV	nREM	REM	SS
aurical	—	0,929	0,399	-0,039	-0,441	0,394	0,324
rectal	0,929	—	0,390	-0,022	-0,477	0,384	0,351
HR	0,399	0,390	—	-0,035	-0,462	0,224	0,263
HRV	-0,039	-0,022	-0,035	—	0,127	-0,128	-0,260
nREM	-0,441	-0,477	-0,462	0,127	—	-0,781	-0,420
REM	0,394	0,384	0,224	-0,128	-0,781	—	0,222
SS	0,324	0,351	0,263	-0,260	-0,420	0,222	—

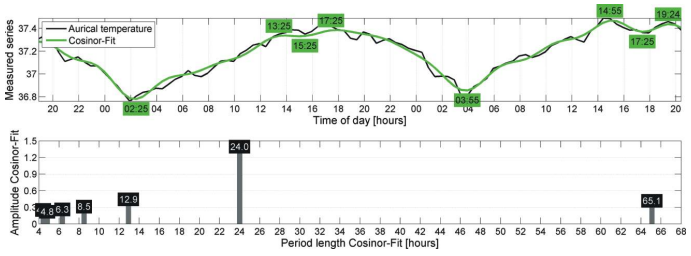
Tab. 3: Correlation coefficents of averaged sleep-episode measures of subject n° 1 (not displayed)

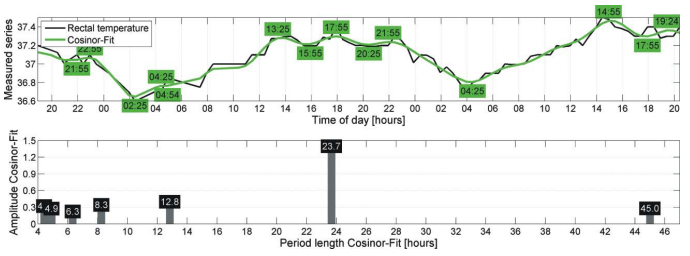
	aurical	rectal	HR	HRV	nREM	REM	SS
aurical	—	0,937	0,576	-0,123	-0,467	0,351	0,811
rectal	0,937	—	0,521	-0,095	-0,469	0,356	0,877
HR	0,576	0,521	—	0,276	-0,209	0,149	0,457
HRV	-0,123	-0,095	0,276	—	0,219	-0,234	-0,014
nREM	-0,467	-0,469	-0,209	0,219	—	-0,795	-0,447
REM	0,351	0,356	0,149	-0,234	-0,795	—	0,348
SS	0,811	0,877	0,457	-0,014	-0,447	0,348	—

Tab. 4: Correlation coefficents of averaged sleep-episode measures of all 8 completed subjects.

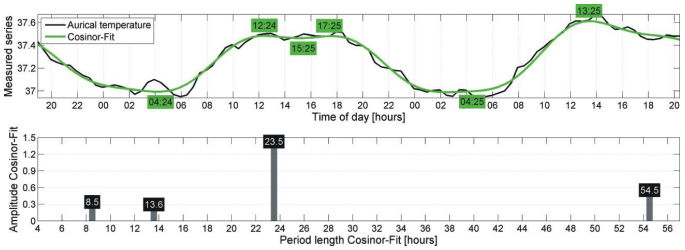
	aurical	rectal	HR	HRV	nREM	REM	SS
aurical	—	0,903	0,537	0,060	-0,363	0,194	0,418
rectal	0,903	—	0,530	0,007	-0,408	0,203	0,489
HR	0,537	0,530	—	0,136	-0,400	0,193	0,433
HRV	0,060	0,007	0,136	—	0,066	-0,081	-0,114
nREM	-0,363	-0,408	-0,400	0,066	—	-0,703	-0,412
REM	0,194	0,203	0,193	-0,081	-0,703	—	0,177
SS	0,418	0,489	0,433	-0,114	-0,412	0,177	—

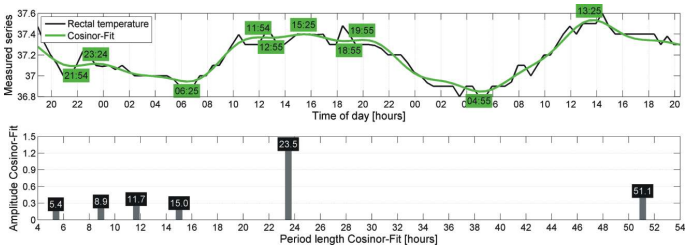
Figs. 8-9: Analysis of periodic elements of sleep-averaged body temperature (left: aurical, right: rectal) of subject n° 4 (see also fig. 6) via COSINOR analysis. Periodic functions were repeatedly fitted to the measured series. Amplitudes of each fitted period component are displayed in the lower panel. Upper panels show original series, overlayed by a fit resulting from adding up all periodic components. Each extremum of the fit is labeled with its occuring time-of-day.





Figs. 10-11: Analysis of periodic elements of sleep-averaged body temperature (left: aurical, right: rectal) of subject n° 12 (see also fig. 7) via COSINOR analysis.





Tab. 5: For each COSINOR-fitted series of every completed subject, period length (respective left column) and amplitude (respective right column) of the strongest periodic component is displayed. For better comparison between rectal and aurical measurement of each subject, the measurement with the stronger (or equal) amplitude is highlighted. The last row contains averaged values.

subject N°	rectal		aurical		HR		HRV		SS		non-REM		REM	
1	23,25	1,20	22,75	1,28	20,67	0,85	18,08	0,75	21,42	0,97	20,58	0,78	19,83	0,54
4	23,67	1,28	24,00	1,28	24,08	0,98	5,75	0,43	8,17	0,54	21,67	0,81	21,00	0,77
5	24,42	1,10	24,92	1,13	11,67	0,42	10,08	0,53	12,58	0,69	33,17	0,81	33,42	0,81
6	22,33	0,98	23,08	1,13	24,50	0,83	22,42	0,57	22,67	1,02	26,75	0,73	27,42	0,54
8	23,25	1,25	23,83	1,24	22,25	0,97	45,75	0,90	45,08	0,88	23,83	0,73	24,58	0,59
10	28,42	1,63	23,17	1,25	6,42	0,77	20,17	0,63	22,50	1,33	30,58	1,38	4,42	0,49
11	22,42	1,19	23,50	1,20	23,58	0,95	13,17	0,42	11,75	0,65	12,75	0,62	43,33	0,50
12	23,50	1,24	23,50	1,31	35,17	0,76	4,92	0,51	21,92	1,10	23,42	0,71	27,08	0,51
	24,01	1,23	23,59	1,23	21,04	0,82	17,34	0,59	20,76	0,90	24,09	0,82	25,14	0,59

CONCLUSIONS

- Body temperature contains strongest circadian components.
- Second strongest circadian modulation is seen in heart rate and subjective sleepiness; the latter also displays distinct ultradian components. However, the course of subjective sleepiness contains the highest inter-individual variability.
- Aurical measurement of body temperature appears superior to rectal measurement: (a) In more cases the amplitude of the aurical circadian component is higher than in the rectal measurement. (b) COSINOR-fit of aurical measurement contains less intermittent extrema than rectal fit. (c) The sensor is more comfortable to wear and less prone to slippingout of place.
- Automated extraction of time-of-day of global circadian maxima and minima via COSINOR-fit is somewhat unreliable because of meaningless intermittent extrema; however, in most cases, extrema in heart rate and subjective sleepiness coincide with extrema of body temperature.
- Reciprocal relationship found between non-REM and REM sleep, significant for almost every subject.